In the problems assume the parameter given in following table. Use the temperature $T = 300$ K unless otherwise stated.

Property	**Si**	**GaAs**	**Ge**
Bandgap Energy	1.12	1.42	0.66
Dielectric Constant	11.7	13.1	16.0
Effective density of states in conduction band $N_c(\text{cm}^{-3})$	2.8×10^{19}	4.7×10^{17}	1.04×10^{19}
Effective density of states in valence band $N_v(\text{cm}^{-3})$	1.04×10^{19}	7.0×10^{18}	6.0×10^{18}
Intrinsic carrier concertration n_i (cm^{-3})	1.5×10^{10}	1.8×10^{6}	2.4×10^{18}
Mobility Electron Hole	 1350 480	 8500 400	 3900 1900

1. In germanium semiconductor material at $T = 400$ K the intrinsic concentration is

(A) 26.8×10^{14} cm^{-3} (B) 18.4×10^{14} cm^{-3}

(C) 8.5×10^{14} cm^{-3} (D) 3.6×10^{14} cm^{-3}

2. The intrinsic carrier concentration in silicon is to be no greater than $n_i = 1\times10^{12}$ cm^{-3}. The maximum temperature allowed for the silicon is (Assume $E_g = 1.12$ eV)

(A) 300 K (B) 360 K

(C) 382 K (D) 364 K

3. Two semiconductor material have exactly the same properties except that material A has a bandgap of 1.0 eV and material B has a bandgap energy of 1.2 eV. The ratio of intrinsic concentration of material A to that of material B is

(A) 2016 (B) 47.5

(C) 58.23 (D) 1048

4. In silicon at $T = 300$ K the thermal-equilibrium concentration of electron is $n_0 = 5\times10^4$ cm^{-3}. The hole concentration is

(A) 4.5×10^{15} cm^{-3} (B) 4.5×10^{15} m^{-3}

(C) 0.3×10^{-6} cm^{-3} (D) 0.3×10^{-6} m^{-3}

5. In silicon at $T = 300$ K if the Fermi energy is 0.22 eV above the valence band energy, the value of p_0 is

(A) 2×10^{15} cm^{-3} (B) 10^{15} cm^{-3}

(C) 3×10^{15} cm^{-3} (D) 4×10^{15} cm^{-3}

6. The thermal-equilibrium concentration of hole p_0 in silicon at $T = 300$ K is 10^{15} cm^{-3}. The value of n_0 is

(A) 3.8×10^{8} cm^{-3} (B) 4.4×10^{4} cm^{-3}

(C) 2.6×10^{4} cm^{-3} (D) 4.3×10^{8} cm^{-3}

7. In germanium semiconductor at $T = 300$ K, the acceptor concentrations is $N_a = 10^{13}$ cm^{-3} and donor concentration is $N_d = 0$. The thermal equilibrium concentration p_0 is

(A) 2.97×10^{9} cm^{-3} (B) 2.68×10^{12} cm^{-3}

(C) 2.95×10^{13} cm^{-3} (D) 2.4 cm^{-3}

Statement for Q.8-9:

In germanium semiconductor at $T = 300$ K, the impurity concentration are

$$N_d = 5\times10^{15}\ \text{cm}^{-3} \text{ and } N_a = 0$$

8. The thermal equilibrium electron concentration n_0 is

(A) 5×10^{15} cm^{-3} (B) 1.15×10^{11} cm^{-3}

(C) 1.15×10^{9} cm^{-3} (D) 5×10^{6} cm^{-3}

9. The thermal equilibrium hole concentration p_0 is

(A) 3.96×10^{13} (B) 1.95×10^{13} cm^{-3}

(C) 4.36×10^{12} cm^{-3} (D) 3.96×10^{13} cm^{-3}

10. A sample of silicon at $T = 300$ K is doped with boron at a concentration of 2.5×10^{13} cm^{-3} and with arsenic at a concentration of 1×10^{13} cm^{-3}. The material is

(A) p-type with $p_0 = 1.5 \times 10^{13}$ cm^{-3}

(B) p-type with $p_0 = 1.5 \times 10^{7}$ cm^{-3}

(C) n-type with $n_0 = 1.5 \times 10^{13}$ cm^{-3}

(D) n-type with $n_0 = 1.5 \times 10^{7}$ cm^{-3}

11. In a sample of gallium arsenide at $T = 200$ K, $n_0 = 5p_0$ and $N_a = 0$. The value of n_0 is

(A) 9.86×10^{9} cm^{-3} (B) 7 cm^{-3}

(C) 4.86×10^{3} cm^{-3} (D) 3 cm^{-3}

12. Germanium at $T = 300$ K is uniformly doped with an acceptor concentration of $N_a = 10^{15}$ cm^{-3} and a donor concentration of $N_d = 0$. The position of fermi energy with respect to intrinsic Fermi level is

(A) 0.02 eV (B) 0.04 eV

(C) 0.06 eV (D)0.08 eV

13. In germanium at $T = 300$ K, the donor concentration are $N_d = 10^{14}$ cm^{-3} and $N_a = 0$. The Fermi energy level with respect to intrinsic Fermi level is

(A) 0.04 eV (B) 0.08 eV

(C) 0.42 eV (D) 0.86 eV

14. A GaAs device is doped with a donor concentration of 3×10^{15} cm^{-3}. For the device to operate properly, the intrinsic carrier concentration must remain less than 5% of the total concentration. The maximum temperature on that the device may operate is

(A) 763 K (B) 942 K

(C) 486 K (D) 243 K

15. For a particular semiconductor at $T = 300$ K $E_g = 1.5$ eV, $m_p^* = 10m_n^*$ and $n_i = 1 \times 10^{15}$ cm^{-3}. The position of Fermi level with respect to the center of the bandgap is

(A) +0.045 eV (B) -0.046 eV

(C) +0.039 eV (D) -0.039 eV

16. A silicon sample contains acceptor atoms at a concentration of $N_a = 5 \times 10^{15}$ cm^{-3}. Donor atoms are added forming and n-type compensated semiconductor such that the Fermi level is 0.215 eV below the conduction band edge. The concentration of donors atoms added are

(A) 1.2×10^{16} cm^{-3} (B) 4.6×10^{16} cm^{-3}

(C) 3.9×10^{12} cm^{-3} (D) 2.4×10^{12} cm^{-3}

17. A silicon semiconductor sample at $T = 300$ K is doped with phosphorus atoms at a concentrations of 10^{15} cm^{-3}. The position of the Fermi level with respect to the intrinsic Fermi level is

(A) 0.3 eV (B) 0.2 eV

(C) 0.1 eV (D) 0.4 eV

18. A silicon crystal having a cross-sectional area of 0.001 cm^2 and a length of 20 μm is connected to its ends to a 20 V battery. At $T = 300$ K, we want a current of 100 mA in crystal. The concentration of donor atoms to be added is

(A) 2.4×10^{13} cm^{-3} (B) 4.6×10^{13} cm^{-3}

(C) 7.8×10^{14} cm^{-3} (D) 8.4×10^{14} cm^{-3}

19. The cross sectional area of silicon bar is 100 μm^2. The length of bar is 1 mm. The bar is doped with arsenic atoms. The resistance of bar is

(A) 2.58 mΩ (B) 11.36 kΩ

(C) 1.36 mΩ (D) 24.8 kΩ

20. A thin film resistor is to be made from a GaAs film doped n-type. The resistor is to have a value of 2 kΩ. The resistor length is to be 200 μm and area is to be 10^{-6} cm^2. The doping efficiency is known to be 90%. The mobility of electrons is 8000 cm^2/V–s. The doping needed is

(A) 8.7×10^{15} cm^{-3} (B) 8.7×10^{21} cm^{-3}

(C) 4.6×10^{15} cm^{-3} (D) 4.6×10^{21} cm^{-3}

21. A silicon sample doped n-type at 10^{18} cm^{-3} have a resistance of 10 Ω. The sample has an area of 10^{-6}

cm^2 and a length of 10 μm. The doping efficiency of the sample is ($\mu_n = 800$ $cm^2/V-s$)

(A) 43.2% (B) 78.1%

(C) 96.3% (D) 54.3%

22. Six volts is applied across a 2 cm long semiconductor bar. The average drift velocity is 10^4 cm/s. The electron mobility is

(A) 4396 $cm^2/V-s$ (B) 3×10^4 $cm^2/V-s$

(C) 6×10^4 $cm^2/V-s$ (D) 3333 $cm^2/V-s$

23. For a particular semiconductor material following parameters are observed:

$\mu_n = 1000$ $cm^2/V-s$,

$\mu_p = 600$ $cm^2/V-s$,

$N_c = N_v = 10^{19}$ cm^{-3}

These parameters are independent of temperature. The measured conductivity of the intrinsic material is $\sigma = 10^{-6}(\Omega-cm)^{-1}$ at $T = 300$ K. The conductivity at $T = 500$ K is

(A) 2×10^{-4} $(\Omega-cm)^{-1}$ (B) 4×10^{-5} $(\Omega-cm)^{-1}$

(C) 2×10^{-5} $(\Omega-cm)^{-1}$ (D) 6×10^{-3} $(\Omega-cm)^{-1}$

24. An n-type silicon sample has a resistivity of 5 $\Omega-cm$ at $T = 300$ K. The mobility is $\mu_n = 1350$ $cm^2/V-s$. The donor impurity concentration is

(A) 2.86×10^{-14} cm^{-3} (B) 9.25×10^{14} cm^{-3}

(C) 11.46×10^{15} cm^{-3} (D) 1.1×10^{-15} cm^{-3}

25. In a silicon sample the electron concentration drops linearly from 10^{18} cm^{-3} to 10^{16} cm^{-3} over a length of 2.0 μm. The current density due to the electron diffusion current is ($D_n = 35$ cm^2/s).

(A) 9.3×10^4 A/cm^2 (B) 2.8×10^4 A/cm^2

(C) $9.3\times10^9 A/cm^2$ (D) 2.8×10^9 A/cm^2

26. In a GaAs sample the electrons are moving under an electric field of 5 kV/cm and the carrier concentration is uniform at 10^{16} cm^{-3}. The electron velocity is the saturated velocity of 10^7 cm/s. The drift current density is

(A) 1.6×10^4 A/cm^2 (B) 2.4×10^4 A/cm^2

(C) $1.6\times10^8 A/cm^2$ (D) 2.4×10^8 A/cm^2

27. For a sample of GaAs scattering time is $\tau_{sc} = 10^{-13}$ s and electron's effective mass is $m_e^* = 0.067 m_o$. If an electric field of 1 kV/cm is applied, the drift velocity produced is

(A) 2.6×10^6 cm/s (B) 263 cm/s

(C) 14.8×10^6 cm/s (D) 482

28. A gallium arsenide semiconductor at $T = 300$ K is doped with impurity concentration $N_d = 10^{16}$ cm^{-3}. The mobility μ_n is 7500 $cm^2/V-s$. For an applied field of 10 V/cm the drift current density is

(A) 120 A/cm^2 (B) 120 A/cm^2

(C) 12×10^4 A/cm^2 (D) $12\times10^4 A/cm^2$

29. In a particular semiconductor the donor impurity concentration is $N_d = 10^{14}$ cm^{-3}. Assume the following parameters,

$\mu_n = 1000$ $cm^2/V-s$,

$$N_c = 2\times10^{19}\left(\frac{T}{300}\right)^{3/2} \text{ cm}^{-3},$$

$$N_v = 1\times10^{19}\left(\frac{T}{300}\right)^{3/2} \text{ cm}^{-3},$$

$E_g = 1.1$ eV.

An electric field of $E = 10$ V/cm is applied. The electric current density at 300 K is

(A) 2.3 A/cm^2 (B) 1.6 A/cm^2

(C) 9.6 A/cm^2 (D) 3.4 A/cm^2

Statement for Q.30-31:

A semiconductor has following parameter

$\mu_n = 7500$ $cm^2/V-s$,

$\mu_p = 300$ $cm^2/V-s$,

$n_i = 3.6\times10^{12}$ cm^{-3}

30. When conductivity is minimum, the hole concentration is

(A) 7.2×10^{11} cm^{-3} (B) 1.8×10^{13} cm^{-3}

(C) 1.44×10^{11} cm^{-3} (D) 9×10^{13} cm^{-3}

31. The minimum conductivity is

(A) 0.6×10^{-3} $(\Omega-cm)^{-1}$ (B) 1.7×10^{-3} $(\Omega-cm)^{-1}$

(C) 2.4×10^{-3} $(\Omega-cm)^{-1}$ (D) 6.8×10^{-3} $(\Omega-cm)^{-1}$

32. A particular intrinsic semiconductor has a resistivity of 50 $(\Omega-\text{cm})$ at $T=300$ K and 5 $(\Omega-\text{cm})$ at $T=330$ K. If change in mobility with temperature is neglected, the bandgap energy of the semiconductor is

(A) 1.9 eV (B) 1.3 eV

(C) 2.6 eV (D) 0.64 eV

33. Three scattering mechanism exist in a semiconductor. If only the first mechanism were present, the mobility would be 500 $\text{cm}^2/\text{V}-\text{s}$. If only the second mechanism were present, the mobility would be 750 $\text{cm}^2/\text{V}-\text{s}$. If only third mechanism were present, the mobility would be 1500 $\text{cm}^2/\text{V}-\text{s}$. The net mobility is

(A) 2750 $\text{cm}^2/\text{V}-\text{s}$ (B) 1114 $\text{cm}^2/\text{V}-\text{s}$

(C) 818 $\text{cm}^2/\text{V}-\text{s}$ (D) 250 $\text{cm}^2/\text{V}-\text{s}$

34. In a sample of silicon at $T=300$ K, the electron concentration varies linearly with distance, as shown in fig. P2.1.34. The diffusion current density is found to be $J_n=0.19$ A/cm^2. If the electron diffusion coefficient is $D_n=25$ cm^2/s, The electron concentration at is

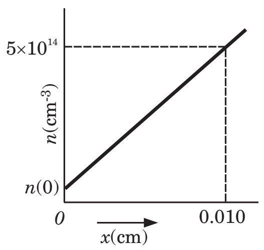

Fig. P2.1.34

(A) 4.86×10^{8} cm^{-3} (B) 2.5×10^{13} cm^{-3}

(C) 9.8×10^{26} cm^{-3} (D) 5.4×10^{15} cm^{-3}

35. The hole concentration in p-type GaAs is given by

$$p=10^{16}\left(1-\frac{x}{L}\right)\text{cm}^{-3} \text{ for } 0\le x\le L$$

where $L=10$ μm. The hole diffusion coefficient is 10 cm^2/s. The hole diffusion current density at $x=5$ μm is

(A) 20 A/cm^2 (B) 16 A/cm^2

(C) 24 A/cm^2 (D) 30 A/cm^2

36. For a particular semiconductor sample consider following parameters:

Hole concentration $p_0=10^{15}e^{\left(\frac{-x}{L_p}\right)}$ $\text{cm}^{-3}, x\ge0$

Electron concentration $n_0=5\times10^{14}e^{\left(\frac{-x}{L_n}\right)}$ $\text{cm}^{-3}, x\le0$

Hole diffusion coefficient $D_p=10$ cm^2/s

Electron diffusion coefficients $D_n=25$ cm^2/s

Hole diffusion length $L_p=5\times10^{-4}$ cm,

Electron diffusion length $L_n=10^{-3}$ cm

The total current density at $x=0$ is

(A) 1.2 A/cm^2 (B) 5.2 A/cm^2

(C) 3.8 A/cm^2 (D) 2 A/cm^2

37. A germanium Hall device is doped with 5×10^{15} donor atoms per cm^3 at $T=300$ K. The device has the geometry $d=5\times10^{-3}$ cm, $W=2\times10^{-2}$ cm and $L=0.1$ cm. The current is $I_x=250$ μA, the applied voltage is $V_x=100$ mV, and the magnetic flux is $B_z=5\times10^{-2}$ tesla. The Hall voltage is

(A) –0.31mV (B) 0.31 mV

(C) 3.26 mV (D) –3.26 mV

Statement for Q.38-39:

A silicon Hall device at $T=300$ K has the geometry $d=10^{-3}$ cm , $W=10^{-2}$ cm, $L=10^{-1}$ cm. The following parameters are measured: $I_x=0.75$ mA, $V_x=15$ V, $V_H=+5.8$ mV, tesla

38. The majority carrier concentration is

(A) 8×10^{15} cm^{-3}, n-type

(B) 8×10^{15} cm^{-3}, p-type

(C) 4×10^{15} cm^{-3}, n-type

(D) 4×10^{15} cm^{-3}, p-type

39. The majority carrier mobility is

(A) 430 $\text{cm}^2/\text{V}-\text{s}$ (B) 215 $\text{cm}^2/\text{V}-\text{s}$

(C) 390 $\text{cm}^2/\text{V}-\text{s}$ (D) 195 $\text{cm}^2/\text{V}-\text{s}$

40. In a semiconductor $n_0=10^{15}$ cm^{-3} and $n_i=10^{10}$ cm^{-3}. The excess-carrier life time is 10^{-6} s. The excess hole concentration is $\delta p=4\times10^{13}$ cm^{-3}. The electron-hole recombination rate is

(A) 4×10^{19} $\text{cm}^{-3}\text{s}^{-1}$ (B) 4×10^{14} $\text{cm}^{-3}\text{s}^{-1}$

(C) 4×10^{24} $\text{cm}^{-3}\text{s}^{-1}$ (D) 4×10^{11} $\text{cm}^{-3}\text{s}^{-1}$

41. A semiconductor in thermal equilibrium, has a hole concentration of $p_0 = 10^{16}$ cm^{-3} and an intrinsic concentration of $n_i = 10^{10}$ cm^{-3}. The minority carrier life time is 4×10^{-7}s. The thermal equilibrium recombination rate of electrons is

(A) 2.5×10^{22} cm^{-3} s^{-1} (B) 5×10^{10} cm^{-3} s^{-1}

(C) 2.5×10^{10} cm^{-3} s^{-1} (D) 5×10^{22} cm^{-3} s^{-1}

Statement for Q.42-43:

A n-type silicon sample contains a donor concentration of $N_d = 10^6$ cm^{-3}. The minority carrier hole lifetime is $\tau_{p0} = 10$ μs.

42. The thermal equilibrium generation rate of hole is

(A) 5×10^8 cm^{-3} s^{-1} (B) 10^4 cm^{-3} s^{-1}

(C) 2.25×10^9 cm^{-3} s^{-1} (D) 10^3 cm^{-3} s^{-1}

43. The thermal equilibrium generation rate for electron is

(A) 1.125×10^9 cm^{-3} s^{-1} (B) 2.25×10^9 cm^{-3} s^{-1}

(C) 8.9×10^{-10} cm^{-3} s^{-1} (D) 4×10^9 cm^{-3} s^{-1}

44. A n-type silicon sample contains a donor concentration of $N_d = 10^{16}$ cm^{-3}. The minority carrier hole lifetime is $\tau_{p0} = 20$ μs. The lifetime of the majority carrier is ($n_i = 1.5 \times 10^{10}$ cm^{-3})

(A) 8.9×10^6 s (B) 8.9×10^{-6} s

(C) 4.5×10^{-17} s (D) 1.13×10^{-7} s

45. In a silicon semiconductor material the doping concentration are $N_a = 10^{16}$ cm^{-3} and $N_a = 0$. The equilibrium recombination rate is $R_{p0} = 10^{11}$ cm^{-3}s^{-1}. A uniform generation rate produces an excess- carrier concentration of $\delta n = \delta p = 10^{14}$ cm^{-3}. The factor, by which the total recombination rate increase is

(A) 2.3×10^{13} (B) 4.4×10^{13}

(C) 2.3×10^9 (D) 4.4×10^9

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Solutions

1. (D) $n_i^2 = N_c N_v \, e^{-\left(\frac{-E_g}{kT}\right)}$

$V_t = 0.0259\left(\frac{400}{300}\right) = 0.0345$

For Ge at 300 K,

$N_c = 1.04 \times 10^{19}$, $N_v = 6.0 \times 10^{18}$, $E_g = 0.66$ eV

$$n_i^2 = 1.04 \times 10^{19} \times 6.0 \times 10^{18} \times \left(\frac{400}{300}\right)^3 \times e^{-\left(\frac{0.66}{0.0345}\right)}$$

$\Rightarrow \quad n_i = 8.5 \times 10^{14}$ cm^{-3}

2. (C) $n_i^2 = N_c N_v \, e^{-\left(\frac{-E_g}{kT}\right)}$

$$(10^{12})^2 = 2.8 \times 10^{19} \times 1.04 \times 10^{19}\left(\frac{T}{300}\right)^3 e^{-\left(\frac{1.12e}{kT}\right)}$$

$T^3 \, e^{\frac{-13 \times 10^3}{T}} = 9.28 \times 10^{-8}$, By trial $T = 382$ K

3. (B) $\dfrac{n_{iA}^2}{n_{iB}^2} = \dfrac{e^{-\frac{E_{gA}}{kT}}}{e^{-\frac{E_{gB}}{kT}}} = e^{-\left(\frac{E_{gA} - E_{gB}}{kT}\right)} = 2257.5 \quad \Rightarrow \quad \dfrac{n_{iA}}{n_{iB}} = 47.5$

4. (A) $p_0 = \dfrac{n_i^2}{n_0} = \dfrac{(1.5 \times 10^{10})^2}{5 \times 10^4} = 4.5 \times 10^{15}$ cm^{-3}

5. (A) $p_0 = N_v \, e^{-\frac{(E_F - E_v)}{kT}} = 1.04 \times 10^{19} \, e^{\frac{-0.22}{0.0259}} = 2 \times 10^{15}$ cm^{-3}

6. (B) $p_0 = N_v \, e^{-\frac{(E_F - E_v)}{kT}} \quad \Rightarrow \quad E_F - E_v = kT \ln\left(\dfrac{N_v}{p_0}\right)$

At 300 K, $N_v = 1.0 \times 10^{19}$ cm^{-3}

$E_F - E_v = 0.0259 \ln\left(\dfrac{1.04 \times 10^{19}}{10^{15}}\right) = 0.239$ eV

$n_0 = N_c \, e^{\frac{(E_c - E_F)}{kT}}$

At 300 K, $N_c = 2.8 \times 10^{19}$ cm^{-3}

$E_c - E_F = 1.12 - 0.239 = 0.881$ eV

$n_0 = 4.4 \times 10^4$ cm^{-3}

7. (C) $p_0 = \dfrac{N_a - N_d}{2} + \sqrt{\left(N_a - \dfrac{N_d}{2}\right)^2 + n_i^2}$

For Ge $n_i = 2.4 \times 10^3$

$$p_0 = \frac{10^{13}}{2} + \sqrt{\left(\frac{10^{13}}{2}\right)^2 + (2.4 \times 10^{13})^2} = 2.95 \times 10^{13} \text{ cm}^{-3}$$

8. (A) $n_0 = \frac{N_d - N_a}{2} + \sqrt{\left(N_d - \frac{N_a}{2}\right)^2 + n_i^2}$

$= \frac{5 \times 10^{15}}{2} + \sqrt{\left(\frac{5 \times 10^{15}}{2}\right)^2 + (2.4 \times 10^{13})^2} = 5 \times 10^{15}$ cm^{-3}

9. (B) $p_0 = \frac{n_i^2}{p_0} = \frac{(2.4 \times 10^{13})^2}{2.95 \times 10^{13}} = 1.95 \times 10^{13}$ cm^{-3}

10. (A) Since $N_a > N_d$, thus material is p-type ,

$p_0 = N_a - N_d = 2.5 \times 10^3 - 1 \times 10^3 = 1.5 \times 10^{13}$ cm^{-3}

11. (D) $kT = 0.0259\left(\frac{200}{300}\right) = 0.0173$ eV

For GaAs at 300 K,

$N_c = 4.7 \times 10^{17}$ cm^{-3}, $N_v = 7.0 \times 10^{18}$, $E_g = 1.42$ eV

$n_i^2 = 4.7 \times 10^{17} \times 7.0 \times 10^{18} \left(\frac{200}{300}\right)^3 e^{-\left(\frac{1.42}{0.0173}\right)}$

$\Rightarrow \quad n_i = 1.48$ cm^{-3}

$n_i^2 = n_0 p_0 = 5 p_0^2 = \frac{n_0^2}{5}$

$n_0 = \sqrt{5} n_i = 3.3$ cm^{-3}

12. (A) $kT = 0.0259\left(\frac{400}{300}\right) = 0.0345$ eV

$n_i^2 = N_c N_v \, e^{-\left(\frac{-E_g}{kT}\right)}$

For Ge at 300 K,

$N_c = 1.04 \times 10^{19}$ cm^{-3} , $N_v = 6 \times 10^{18}$ cm^{-3} , $E_g = 0.66$ eV

$n_i^2 = 1.04 \times 10^{19} \times 6 \times 10^{18} \left(\frac{400}{300}\right)^3 e^{-\left(\frac{0.66}{0.0345}\right)} = 7.274 \times 10^{29}$

$n_i = 8.528 \times 10^{14}$ cm^{-3}

$p_0 = \frac{N_a}{2} + \sqrt{\left(\frac{N_a}{2}\right)^2 + n_i^2}$

$= \frac{10^{15}}{2} + \sqrt{\left(\frac{10^{15}}{2}\right)^2 + 7.274 \times 10^{29}}$

$\Rightarrow \quad p_0 = 1.489 \times 10^{15}$ cm^{-3}

$E_{Fi} - E_F = kT \ln\left(\frac{p_0}{n_0}\right) = 0.0345 \ln\left(\frac{1.489 \times 10^{15}}{8.528 \times 10^{14}}\right)$

$= 0.019$ eV

13. (A) $n_0 = \frac{N_d}{2} + \sqrt{\left(\frac{N_d}{2}\right)^2 + n_i^2}$

For Ge at $T = 300$ K, $n_i = 2.4 \times 10^{13}$ cm^{-3}

$n_0 = \frac{10^{14}}{2} + \sqrt{\left(\frac{10^{14}}{2}\right)^2 + (2.4 \times 10^{13})^2} = 1.055 \times 10^{14}$ cm^{-3}

$E_F - E_{Fi} = kT \ln\left(\frac{n_0}{n_i}\right) = 0.0259 \ln\left(\frac{1.055 \times 10^{14}}{2.4 \times 10^{13}}\right)$

$= 0.0383$ eV

14. (A) $n_0 = \frac{N_d}{2} + \sqrt{\left(\frac{N_d}{2}\right)^2 + n_i^2}$

$n_i = 0.05 n_0$

$\Rightarrow \quad n_0 = 1.5 \times 10^{15} + \sqrt{(1.5 \times 10^{15})^2 + (0.05\, n_0)^2}$

$\Rightarrow \quad n_0 = 3.0075 \times 10^{15}$ cm^{-3}

$n_i = 1.504 \times 10^{14}$ cm^{-3}

$n_i^2 = N_c N_v \, e^{-\left(\frac{-E_g}{kT}\right)}$

For GaAs at $T = 300$ K,

$N_c = 4.7 \times 10^{17}$, $N_v = 7 \times 10^{18}$, $E_g = 1.42$ eV

$(1.504)^2 = 4.7 \times 10^{17} \times 7 \times 10^{18} \left(\frac{T}{300}\right)^3 e^{-\left(\frac{1.42 \times 300}{0.0259 T}\right)}$

By trial and error $T = 763$ K

15. (A) $E_{Fi} - E_{midgap} = \frac{3}{4} kT \ln\left(\frac{m_p^*}{m_p^*}\right) = 0.0446$ eV

16. (A) $n_0 = N_d - N_a = N_c \, e^{-\left(\frac{E_c - E_F}{kT}\right)}$

For Si, $N_c = 2.8 \times 10^{19}$ cm^{-3}

$N_d = 5 \times 10^{15} + 2.8 \times 10^{19} \, e^{-\left(\frac{0.215}{0.0259}\right)} = 1.19 \times 10^{16}$ cm^{-3}

17. (A) $E_F - E_{Fi} = kT \ln\left(\frac{N_d}{N_i}\right)$

$= 0.0259 \ln\left(\frac{10^{15}}{1.5 \times 10^{10}}\right) = 0.287$ eV

18. (D) $R = \frac{V}{I} = \frac{20}{100\text{m}} = 200\ \Omega$

$\sigma = \frac{L}{RA} = \frac{2 \times 10^{-3}}{(200)(0.001)} = 0.01(\Omega - \text{cm})^{-1}$

$\sigma \approx e\mu_n n_0$, For Si, $\mu_n = 1350$.

$\Rightarrow \quad 0.01 = (1.6 \times 10^{-19})(1350) n_0$

$n_0 = 4.6 \times 10^{13}$ cm^{-3},

$n_0 >> n_i \quad \Rightarrow \quad n_0 = N_d$

19. (B) $N_d >> n_i \quad \Rightarrow \quad n_0 = N_d$, $\sigma \approx e\,\mu_n n_0$,

$R = \frac{L}{\sigma A} = \frac{L}{e\mu_n N_d A}$,

$$=\frac{0.1}{(1.6\times10^{-19})(1100)(5\times10^{16})(100\times10^{-8})}=11.36\ \text{k}\Omega$$

20. (A) $R=\dfrac{L}{\sigma A}$, $\sigma\approx e\,\mu_n n_0$, $R=\dfrac{L}{e\mu_n n_0 A}$

$$\Rightarrow\quad n_0=\frac{L}{e\mu_n AR}$$

$n_0=0.9N_d$

$$=\frac{20\times10^{-4}}{(0.9)(1.6\times10^{-19})(8000)(10^{-6})(2\times10^{3})}=8.7\times10^{15}\ \text{cm}^{-3}$$

21. (B) $\sigma\approx e\,\mu_n n_0$, $R=\dfrac{L}{\sigma A}$, $n_0=\dfrac{L}{e\mu_n AR}$

$$=\frac{10\times10^{-4}}{(1.6\times10^{-19})(800)(10^{-6})(10)}=7.81\times10^{17}\ \text{cm}^{-3}$$

$$\text{Efficiency}=\frac{n_0}{N_d}\times100=\frac{7.8\times10^{17}}{10^{18}}\times100=78.1\ \%$$

22. (D) $E=\dfrac{V}{L}=\dfrac{6}{2}=3$ V/cm, $v_d=\mu_n E$,

$$\mu_n=\frac{v_d}{E}=\frac{10^4}{3}=3333\ \text{cm}^2/\text{V}-\text{s}$$

23. (D) $\sigma_1=en_i(\mu_n+\mu_p)$

$10^{-6}=(1.6\times10^{-19})(1000+600)n_i$

At $T=300$ K, $n_i=3.91\times10^{9}\ \text{cm}^{-3}$

$$n_i^2=N_cN_v\,e^{-\left(\frac{E_g}{kT}\right)}\quad\Rightarrow E_g=kT\ln\left(\frac{N_cN_v}{n_i^2}\right)$$

$$\Rightarrow E_g=2(0.0259)\ln\left(\frac{10^{19}}{3.91\times10^{9}}\right)=1.122\ \text{eV}$$

At $T=500$ K, $kT=0.0259\left(\dfrac{500}{300}\right)=0.0432$ eV,

$$n_i^2=(10^{19})^2\,e^{-\left(\frac{1.122}{0.0432}\right)}\ \text{cm}^{-3},$$

$\Rightarrow\quad n_i=2.29\times10^{13}\ \text{cm}^{-3}$

$=(1.6\times10^{-19})(2.29\times10^{13})(1000+600)$

$=5.86\times10^{-3}(\Omega-\text{cm})^{-1}$

24. (B) $\rho=\dfrac{1}{\sigma}=\dfrac{1}{e\mu_n N_d}$

$$N_d=\frac{1}{\rho e\mu_n}=\frac{1}{5(1.6\times10^{-19})(1350)}=9.25\times10^{14}\ \text{cm}^{-3}$$

25. (B) $J_n=eD_n\dfrac{dn}{dx}$

$$=(1.6\times10^{-19})(35)\left(\frac{10^{18}-10^{16}}{2\times10^{-4}}\right)=2.8\times10^{4}\ \text{A/cm}^2$$

26. (A) $J=evn=(1.6\times10^{-19})(10^7)(10^{16})=1.6\ \text{A/cm}^2$

27. (A) $v_d=\dfrac{e\tau_{sc}E}{m_e^*}=\dfrac{(1.6\times10^{-19})(10^{-13})(10^5)}{(0.067)(9.1\times10^{-31})}$

$=26.2\times10^{3}\ \text{m/s}=2.6\times10^{6}\ \text{cm/s}$

28. (A) $N_d>>n_i\quad\Rightarrow\quad n_0=N_d$

$J=e\mu_n n_0E=(1.6\times10^{-19})(7500)(10^{16})(10)=120\ \text{A/cm}^2$

29. (D) $n_i^2=N_cN_v\,e^{-\left(\frac{-E_g}{kT}\right)}$

$$=(2\times10^{19})(1\times10^{19})\,e^{-\left(\frac{1.1}{0.0259}\right)}=7.18\times10^{19}$$

$\Rightarrow\quad n_i=8.47\times10^{9}\ \text{cm}^{-3}$

$N_d>>n_i\quad\Rightarrow\quad N_d=n_0$

$J=\sigma E=e\mu_n n_0E$

$=(1.6\times10^{-19})(1000)(10^{14})(100)=1.6\ \text{A/cm}^2$

30. (A) $\sigma=e\mu_n n_0+e\mu_p p_0$ and $n_0=\dfrac{n_i^2}{p_0}$

$$\Rightarrow\quad\sigma=e\mu_n\frac{n_i^2}{p_0}+e\mu_p p_0,$$

$$\frac{d\sigma}{dp_0}=0=\frac{(-1)e\mu_n n_i^2}{p_0^2}+e\mu_p$$

$$\Rightarrow\quad p_0=n_i\left(\frac{\mu_n}{\mu_p}\right)^{\frac{1}{2}}=3.6\times10^{12}\left(\frac{7500}{300}\right)^{\frac{1}{2}}$$

$=7.2\times10^{11}\ \text{cm}^{-3}$

31. (B) $\sigma_{min}=\dfrac{2\sigma_i\sqrt{\mu_p\mu_n}}{\mu_p+\mu_n}=2\,en_i\sqrt{\mu_p\mu_n}$

$=2\times1.6\times10^{-19}(3.6\times10^{12})\sqrt{(7500)(300)}$

$=1.7\times10^{-3}(\Omega-\text{cm})^{-1}$

32. (B) $\sigma=\dfrac{1}{\rho}=e\mu n_i$,

$$\frac{\frac{1}{\rho_1}}{\frac{1}{\rho_2}}=\frac{n_{i1}}{n_{i2}}=\frac{e^{-\frac{E_g}{2kT_1}}}{e^{-\frac{E_g}{2kT_2}}}$$

$$0.1=e^{-\frac{E_g}{2k}\left(\frac{1}{T_1}-\frac{1}{T_2}\right)}$$

$$\frac{E_g}{2k}\left(\frac{330-300}{330\times300}\right)=\ln 10$$

$E_g=22(k300)\ln 10=1.31$ eV

33. (D) $\dfrac{1}{\mu}=\dfrac{1}{\mu_1}+\dfrac{1}{\mu_2}+\dfrac{1}{\mu_3}$

$$\frac{1}{\mu}=\frac{1}{500}+\frac{1}{750}+\frac{1}{1500} \quad \Rightarrow \quad \mu=250\ \text{cm}^2/\text{V}-\text{s}$$

34. (B) $J_n=eD_n\dfrac{dn}{dx}$

$$0.19=(1.6\times10^{-19})(25)\left(\frac{5\times10^{14}-n(0)}{0.010}\right),$$

$n(0)=2.5\times10^{13}\ \text{cm}^{-3}$

35. (B) $J=-eD_p\dfrac{dp}{dx}=-eD_p\dfrac{d}{dx}\left(10^{16}\left(1-\dfrac{x}{L}\right)\right)=\dfrac{e10^{16}D_p}{L}$

$$=\frac{(1.6\times10^{-19})(10^{16})(10)}{10\times10^{-4}}$$

$J=16\ \text{A/cm}^2$

36. (B) $J_p=-eD_p\dfrac{dp_0}{dx}\bigg|_{x=0}=\dfrac{10^{15}eD_p}{L_p}$

$$J_n=e\,D_n\frac{dn_0}{dx}\bigg|_{x=0}=\frac{5\times10^{14}eD_n}{L_n}$$

$$J=J_p+J_n=\frac{10^{15}eD_p}{L_p}+\frac{5\times10^{14}eD_n}{L_n}$$

$$=1.6\times10^{-19}\left(\frac{10^{15}(10)}{15\times10^{-4}}+\frac{5\times10^{14}(25)}{10^{-3}}\right)=5.2\ \text{A/cm}^2$$

37. (A) $V_H=\dfrac{-I_xB_z}{ned}$

$$=\frac{(250\times10^{-6})(5\times10^{-2})}{(5\times10^{21})(1.6\times10^{-19})(5\times10^{-5})}=-0.313\ \text{mV}$$

38. (B) V_H is positive p-type

$$V_H=\frac{I_xB_z}{epd} \Rightarrow \quad p=\frac{I_xB_z}{eV_Hd}$$

$$p=\frac{(0.75\times10^{-3})(10^{-1})}{(1.6\times10^{-19})(5.8\times10^{-3})(10^{-5})}$$

$=8.08\times10^{21}\ \text{m}^{-3}=8.08\times10^{15}\ \text{cm}^{-3}$

39. (C) $u_p=\dfrac{I_xL}{epV_xWd}$

$$=\frac{(0.75\times10^{-3})(10^{-3})}{(1.6\times10^{-19})(8.08\times10^{21})(15)(10^{-4})(10^{-5})}$$

$\mu_p=3.9\times10^{-2}\ \text{m}^2/\text{V}-\text{s}=390\ \text{cm}^2/\text{V}-\text{s}$

40. (A) n-type semiconductor

$$R=\frac{\delta p}{\tau_{p0}}=\frac{4\times10^{13}}{10^{-6}}=4\times10^{19}\ \text{cm}^{-3}\text{s}^{-1}$$

41. (C) $n_0=\dfrac{n_i^2}{p_0}=\dfrac{(10^{10})^2}{10^{16}}=10^4\ \text{cm}^{-3}$

$$R_{n0}=\frac{n_0}{\tau_{n0}}=\frac{10^4}{4\times10^{-7}}=2.5\times10^{10}\ \text{cm}^{-3}\text{s}^{-1}$$

42. (C) $R_{n0}=\dfrac{p_0}{\tau_{p0}}$, $p_0=\dfrac{n_i^2}{n_0}$, $n_0=N_d=10^6\ \text{cm}^{-3}$

$$p_0=\frac{(1.5\times10^{10})^2}{10^{16}}=2.25\times10^4\ \text{cm}^{-3}$$

$$R_{n0}=\frac{2.25\times10^4}{10\times10^{-6}}=2.25\times10^9\ \text{cm}^{-3}\text{s}^{-1}$$

43. (B) Recombination rate for minority and majority carrier are equal . The generation rate is equal to Recombination rate.

$G=R_{n0}=R_{p0}=2.25\times10^9\ \text{cm}^{-3}\text{s}^{-1}$

44. (A) Recombination rates are equal $\dfrac{n_0}{\tau_{n0}}=\dfrac{p_0}{\tau_{p0}}$,

$N_d>>n_i$

$$n_0=N_d,\ p_0=\frac{n_i^2}{n_0}$$

$$\tau_{n0}=\frac{n_0}{p_0}\tau_{p0}=\frac{n_0^2}{n_i^2}\tau_{p0}$$

$$=\left(\frac{10^{16}}{1.5\times10^{10}}\right)^2\times20\times10^{-6}=8.9\times10^6\ \text{s}$$

45. (D) $N_d>>n_i \quad \Rightarrow \quad n_0=N_d$

$$p_0=\frac{n_i^2}{n_0}=\frac{(1.5\times10^{10})^2}{10^{16}}=2.25\times10^4\ \text{cm}^{-3}$$

$$R_{p0}=\frac{p_0}{\tau_{p0}} \quad \Rightarrow \quad \tau_{p0}=\frac{p_0}{R_{p0}}=\frac{2.25\times10^4}{10^{11}}=2.25\times10^7\ \text{s}$$

$$R_p=\frac{\delta p}{\tau_{p0}}=\frac{10^{14}}{2.25\times10^{-7}}=4.44\times10^{20}\ \text{cm}^{-3}\text{s}^{-1}$$

$$\frac{R_p}{R_{p0}}=\frac{4.44\times10^{20}}{10^{11}}=4.44\times10^9$$

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